# 4398-M
# SEVEN-DIAL DOUBLE RATIO SET

LEEDS & NORTHRUP

## PREFACE

It is assumed that the user of this double ratio set is familiar with the techniques of precision resistance measurement. However, should the user wish to review the basic principles of such measurements, it is recommended that he refer to the following publications:

—Calibration Procedures for Direct Current Resistance Apparatus, Monograph 39, National Bureau of Standards

—Precision Resistors and Their Measurements, Circular 470, National Bureau of Standards

—Notes on the Kelvin Bridge, Notebook E-53(1).

The first two publications can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20525; the third publication can be obtained from the Leeds & Northrup Company.

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## SPECIFICATIONS

USES AND CORRESPONDING LIMITS OF ERROR

Seven-Dial Double Ratio Set for Kelvin Bridge Four-Terminal Measurements

Limit of Error:

20 parts per million (ppm) without corrections.
10 ppm with calibration-report corrections (see Section 6E).
0.2 ppm when measurement is made by direct substitution method in 1:1 ratio.

Direct Reading Ratio Set

Limit of Error:

0.2 ppm when measurement is made by substitution method in 1:1 ratio.

Eight-Dial Resistance Box

Limit of Error:

±0.003% for change from "zero" resistance of approximately 100 ohms. Range is 100 to 2111.1110 ohms; maximum permissible current is 10 milliamperes.

Seven-Dial Double Ratio Set with Auxiliary Resistance Box for Determining Ratios Between Fixed Calibration Points of Resistance Thermometers

Limit of Error:

±0.003% plus instability of auxiliary resistance box.

Lead Compensation Decades

Limit of Error:

±0.1% for 1 ohm decade.
±1% for 0.1 ohm decade.
±0.005 ohm for 0.01 ohm decade.
±0.0005 ohm for 0.001 ohm decade.

A RATIO ARM

Seven Decades.
Range: 100 to 1111.1110 ohms in steps of 0.0001 ohm.

B RATIO ARM

One Decade.
Ten steps of 100 ohms.

TOTAL RESISTANCE

2111.1110 ohms (A plus B ratio arm decades).

RATIO ARMS

Double set for Kelvin bridge measurements; one set used for Wheatstone bridge measurements.

## SPECIFICATIONS

AVAILABLE RATIOS
Continuously adjustable from about 1:11 to 11:1.
Maximum Resolution: 0.1 ppm.

LEADWIRE COMPENSATION
Provided by $L_A$ and $L_B$ decades and yoke adjust control.

$L_A$ decade is a four-dial unit in series with the A ratio arm. Resistance range varies from 1 to 11.110 ohms with adjustability of 0.0002 ohm per smallest division on slidewire.

$L_B$ decade is a two-dial unit in series with the B ratio arm. Resistance range varies from 0 to 11 ohms in steps of 0.1 ohm.

Yoke adjust control is a 0.5 ohm (nominal) ten-turn potentiometer.

DETECTOR KEY
Pushbutton key for connecting external detector.

LEAD BALANCE SWITCH
Shorts out ratio arms when balancing leadwires.

BATTERY SWITCH
Provides normal, off, and reverse positions; normal and reverse positions change polarity of battery connections.
Rating: 20 amperes.

BINDING POSTS
Thirteen binding posts provided: six on top panel for connection of 2- or 4-terminal resistance standards and unknown resistances; seven at rear of ratio set for connection of detector, batteries, and ground, for calibration of ratio arms, and for other uses—such as use as resistance box.

APPLIED VOLTAGE
Not to exceed one volt for each 100 ohm ratio resistor in circuit—for example, 11 volts for 100:1000 ratio.

READOUT
Each decade in the A and B ratio arms has an extra pole which can be wired for printout or display of the decade positions.

CASE
Aluminum; vinyl cover for protection against dust furnished with case.

DIMENSIONS
19" long x 10-1/2" wide x 9-1/2" deep with legs retracted (11" deep with legs extended).

WEIGHT
About 24 pounds.

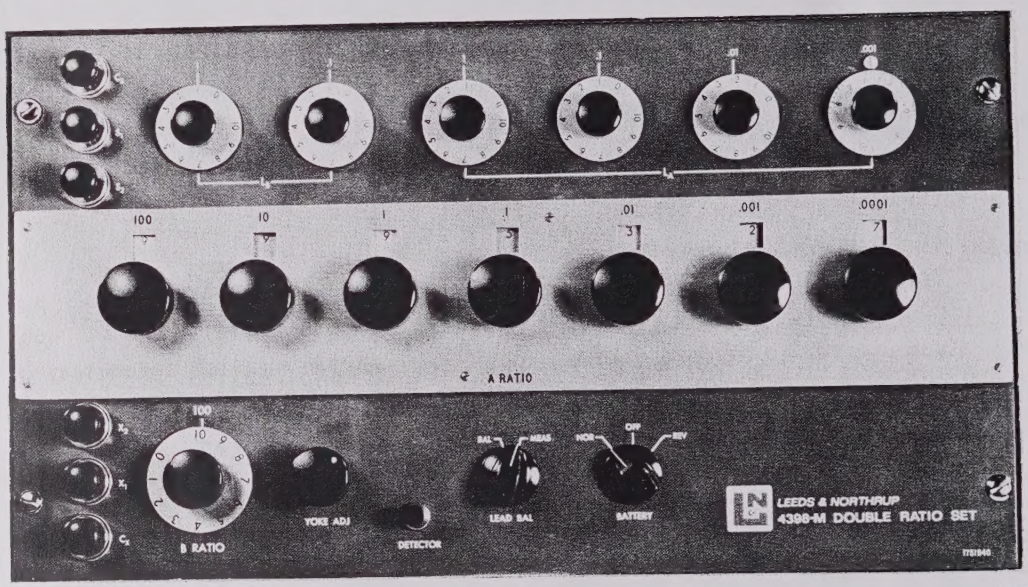


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*Fig. 1–Front view of 4398-M Double Ratio Set.*

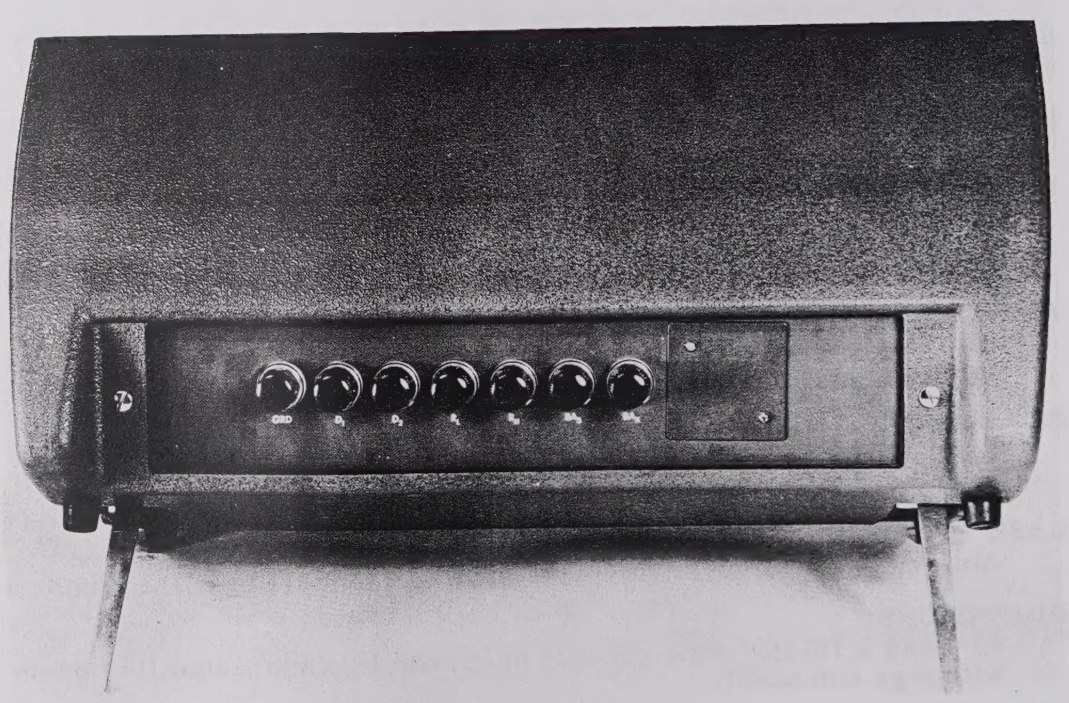

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*Fig. 2–Rear view of 4398-M Double Ratio Set.*

# 4398-M

# SEVEN-DIAL DOUBLE RATIO SET

## 1. INTRODUCTION

The 4398-M Seven-Dial Double Ratio Set (DRS), illustrated in Figs. 1 and 2, is a precision ratio device designed primarily for the calibration of high accuracy dc resistance standards having values from about 0.0001 ohm to 100,000 ohms. It has provisions for four-terminal Kelvin bridge measurements (usually 10 ohms or less) or two-terminal Wheatstone bridge measurements (up to 100,000 ohms), and it can be used as a direct reading ratio set (DRRS). It is also designed to provide leadwire compensation on all measurements and is particularly adaptable for use with electronic type null detectors, such as the L&N 9838 Guarded Nanovolt Detector or the L&N 9834 Electronic DC Null Detector.

The ratio set is designed for bench mounting and is furnished with a vinyl cover that protects it from dust when it is not in use. Its cast aluminum case and top panel form a shield against electrostatic disturbances. This shield becomes effective when the case is grounded through the GRD binding post to a good earth ground. The case is equipped with a pair of spring-loaded retractable legs that permit it to be used in either of two positions. With the legs extended, the top panel is inclined fifty degrees from the horizontal; with the legs retracted, the top panel is inclined thirty degrees from the horizontal.

## 2. AUXILIARY EQUIPMENT

Table I lists the auxiliary equipment recommended for use with this ratio set.

**TABLE I–RECOMMENDED AUXILIARY EQUIPMENT**

| EQUIPMENT | QUANTITY |
|---|---|
| DC Electronic Null Detector or sensitive galvanometer (L&N 9838 or equivalent preferred) | 1 |
| 12-Volt Wet Cell* or 1.5-Volt Dry Cells (L&N Std. 2233-1), where current requirements permit | - |
| 100-Ohm N. B. S. Type Resistance Standards (L&N 4030-B or equivalent) | 11 |
| Mercury Cup Stands (L&N 127287 or equivalent) | 12 |
| Copper Shorting Link (L&N 128436 or equivalent) | 1 |
| Ammeter and Voltmeter to suit requirements of Table III (Triplett Unimeter Kit A* or equivalent) | - |
| Battery rheostat as required to limit current to values indicated in Table III (Resistance of rheostat depends upon type of battery used (12-volt, 1.5-volt, etc.); for example, Ohmite Model 1301* is rated 1000 watts, 1.5 ohms and is adequate for measurements requiring 10 to 20 amperes when a 12-volt battery is used). | - |

*Not L&N stock items.

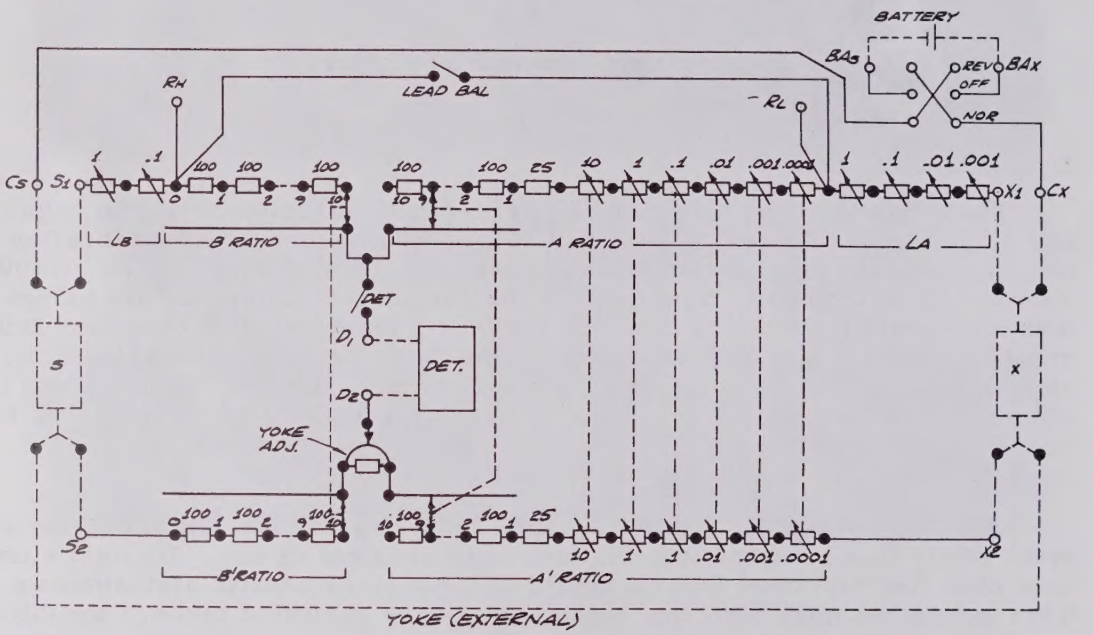


*Fig. 3–Simplified schematic showing typical connections (dashed) for 4-terminal measurements.*

## 3. DESCRIPTION OF CIRCUIT AND MAJOR COMPONENTS

### 3A. Circuit

Fig. 3 is a simplified schematic diagram of the circuit shown on Dwg. L-D-829-30.

As indicated by Fig. 3 and Dwg. L-D-829-30, the bridge ratio arms consist essentially of eight decades, seven of 10 X (100 + 10 + 1 + 0.1 + 0.01 + 0.001 + 0.0001) ohms per step which make up the A ratio, and one of 10 X 100 ohms per step which makes up the B ratio. The A and B decades are mechanically coupled to eight similar decades to form the A' and B' ratio arms of a double ratio set. The A' and B' ratio arms form the "yoke" ratio.

Adjustable resistances $L_A$ and $L_B$ are the lead compensation resistors and are adjustable for a ratio variation from about 1:11 to 11:1.

The Yoke Adjust potentiometer provides the adjustment necessary to make the yoke ratio arms, including the external leads, in the same ratio as that of the battery ratio arms.

Binding posts permit calibration of the ratio arms and permit other uses of the ratio set—for example, as a resistance box.

**TABLE II–SAMPLE READOUTS**

| READING IN WINDOW OF A RATIO DIAL | | | | | | | READOUT |
|---|---|---|---|---|---|---|---|
| 100 | 10 | 1 | .1 | .01 | .001 | .0001 | |
| 5(B) | 2(B) | 3(B) | 4(B) | 5(B) | 6(B) | 7(B) | 523.4567 |
| 10(B) | X(B) | 9(B) | 8(B) | X(B) | 6(B) | 10(B) | 1109.9070 |
| 1(B) | 8(B) | X(B) | 6(B) | X(B) | 3(B) | 8(B) | 190.7038 |
| | 9(R) | 8(R) | 0(R) | 7(R) | 0(R) | X(R) | 98.0710 |

B—indicates black numerals; R—indicates red numerals.

## 3B. Adjustable Arm Decades and Resistance Dials

All decades employ L&N Type 01 Switches with double, paralleled contacts, where required. The L&N Type 01 Switches are enclosed, rotary-type switches with silver-alloy contacts and self-aligning brushes which provide sustained low contact resistance and low thermal emf. Life tests have shown negligible change in contact resistance after several million operations.

The 10-ohm down through the 0.0001-ohm decades of the A ratio are of the Waidner-Wolff (shunt-type) design. This design minimizes the effects of contact resistance, which are of particular importance in the low-resistance decades.

A fixed series resistor of 25 ohms (nominal) in each of the A and A' ratios, in combination with the residual resistances of the Waidner-Wolff decades, results in a minimum resistance of 100 ohms in the A ratio.

The switches controlled by the A and B ratio dials are equipped with an extra switch wafer. These wafers may be wired (-R option) to permit the dial settings of these switches to be sensed by an external readout device.

All A ratio dials except the 100 dial are marked with two sets of numerals: one set (the upper one) being black and the other set (the lower one) being red. An X indicates that the dial reading is equal to 10—that is, the reading should be read as 0 with 1 carried over to the next higher dial. For example, assume that the last three dials indicate 7, X, and X, respectively; the reading of these dials is therefore 810. Table II lists a representative number of sample readouts.

## 3C. Lead Balance Switch

This switch is used to short the battery ratio arms to provide for the balancing of leadwires.

**TABLE III–DETECTOR SENSITIVITIES FOR TYPICAL RESISTANCE COMPARISONS**

| TYPE OF MEASUREMENT | RESISTANCE COMPARISON | BATTERY CURRENT* OR VOLTAGE | 9838 DETECTOR SENSITIVITY** (PPM/DIV) |
|---|---|---|---|
| 4-Terminal DRS | 1:1*** | 0.1A | 0.6 |
| | 1:0.1*** | 0.1A | 1 |
| | 0.1:0.1 | 3A | 0.2 |
| | 0.1:0.01 | 3A | 0.3 |
| | 0.01:0.01 | 10A | 0.6 |
| | 0.01:0.001 | 10A | 1 |
| | 0.001:0.001 | 20A | 3 |
| | 1:10*** | 0.1A | 0.1 |
| | 10:10 | 0.1A | 0.06 |
| | 10:100 | 0.03A | 0.04 |
| | 100:100 | 0.03A | 0.02 |
| 2-Terminal DRRS | 100:100 | 0.03A | 0.01 |
| | 100:1000 | 0.01A | 0.01 |
| | 1000:1000 | 6V | 0.01 |
| | 1000:10,000 | 12V | 0.03 |
| 2-Terminal DRRS Reversed Orientation | 10,000:10,000 | 12V**** | 0.06 |
| | 10,000:100,000 | 12V**** | 0.3 |
| | 100,000:100,000 | 12V**** | 0.5 |
| | 100,000:1,000,000 | 12V**** | 3 |
| | 1,000,000:1,000,000 | 12V**** | 5 |

* All listed battery currents are maximum permissible currents that are consistent with the calibration accuracy of the resistance standards being checked.

** Listed sensitivities are obtainable with the 9838 Sensitivity Control set at 10 (maximum).

*** The one-ohm resistance standard indicated in these comparisons is the L&N4210 Thomas-Type One-Ohm Standard. For higher sensitivity, a 0.3A battery current may be used momentarily after a preliminary balance with a 0.1A battery current.

**** The battery voltage for the reversed orientation may be raised to 100 volts for measurements involving 1,000,000-ohm resistors, if increased sensitivity is desired.

## 3D. Yoke Adjust Control

The yoke adjust control is a shunted 10-turn potentiometer that is used to balance the yoke ratio arms.

## 3E. Detector Key

A pushbutton detector key is provided for connecting the external detector into the ratio set circuit. This pushbutton key can be locked down in its closed position by being turned clockwise.

## 3F. Detector

The detector recommended for use with this ratio set is the high sensitivity 9838 Guarded Nanovolt Detector. The sensitivities that can be obtained with this detector are listed in Table III. All sensitivities are listed with consideration for the maximum permissible current consistent with the calibration accuracy, the ratings of the ratio set components, and the convenience of obtaining a suitable voltage source. Thus, all tabulated measurements can be made by the use of a 12-volt wet cell and a suitable current-limiting resistance.

### 3G. Battery Switch

The battery switch is a high-current-capacity reversing switch, capable of handling 20 amperes. Its normal (NOR) and reverse (REV) positions permit reversing the battery polarity without the aid of an external switch. When the ratio set is not being used, this switch should be set in its OFF position.

The ratio set is carefully designed to reduce the magnitudes of internal parasitic emf's to negligible values. However, parasitic emf's of sufficient magnitude to affect adversely the accuracy of the measurements may be present in the external circuit. To check for their presence, normal and reverse readings are taken—that is, a reading is taken with the battery switch in its NOR position and then a reverse reading is taken with the battery polarity reversed—that is, with the battery switch in its REV position. If parasitic emf's are present, the two readings will not be equal. The elimination of the effect of parasitic emf's is achieved by taking the average of the two readings, or by rebalancing the ratio set until the detector deflection in NOR is the same as that in REV. If an electronic null detector is used, the effects of parasitic emf's (thermals) can be reduced further by zeroing the detector with the battery switch in its OFF position and with the detector key locked down.

### 3H. Binding Posts

The thirteen binding posts of this ratio set are constructed of metal and plastic. The metal parts are made of gold-plated copper, and the plastic parts of acrylonitrile styrene copolymer which affords a high quality insulating medium. Six binding posts are located on the top panel; these posts are provided for the connection of 2 or 4-terminal resistance standards (S) and unknown resistances (X). Seven posts are mounted at the rear of the ratio set for the connection of a detector, batteries, and a ground, for the calibration of the ratio arms, and for other uses of the ratio set—for example, use as a resistance box.

## 4. INSTALLATION

Install the ratio set on a bench or other level surface at a location having a reasonably constant temperature with no sudden changes. For example, sudden changes can occur near heating or air conditioning vents. Make sure that the selected location is free from strong electrostatic and magnetic fields and from vibration.

With the legs retracted, the front panel of this ratio set is inclined thirty degrees from the horizontal, and with the legs extended, the front panel is inclined fifty degrees from the horizontal. To extend the legs, push the end of the shaft that extends through the side of the case, and pull the legs all the way out. To retract them, push the end of the shaft while pushing back one of the legs until both legs are in their retracted positions; then release the shaft to lock the legs in place.

## 5. CONNECTIONS

Connect the resistance standard (S) and the resistance under test (X) to the ratio set with solid copper leadwires. Although the use of leadwire having lengths that have the same ratio as the resistances connected to the ratio set is not necessary, use leadwires that are short and of heavy gage to minimize the effects of ambient temperature changes and stray ac pickup. American wire gage 13 or heavier wire is recommended for the connection of the external resistors.

When using the instrument as a double ratio set for Kelvin measurements of low value resistances, make sure that the external yoke resistance is low in comparison with the value of the test resistance—that is, it is not more than ten times the resistance under test. In applications using mercury stands, one stand can serve as the yoke connection when one arm of the resistance standard and of the resistance under test is placed on the same mercury stand. When it is necessary to open the yoke circuit, place a thin piece of insulating material, about two inches square, under one of the arms to insulate that arm from the mercury cup. Connect the GRD binding post to a good earth ground. When connecting the battery, use a wire size that has a rating consistent with the current to be used during the measurement.

## 6. OPERATION AS A DOUBLE RATIO SET

### 6A. General Information

Operation as a Kelvin double ratio set is required for precision measurements of 10 ohms or less. This type of operation requires four-terminal connections between the resistance under test (unknown) and the ratio set; it also compensates for the resistances of the potential leads of both the standard resistance and the unknown by a lead balancing procedure.

Fig. 3 shows typical connections of four-terminal standard (S) and unknown (X) resistances to the ratio set. Fig. 4, which is a rearrangement of the circuit shown in Fig. 3, identifies the leads and associated resistances that require balancing.

To make a measurement, it is required that the A and B ratio dials be adjusted so that

$$\frac{X}{S} = \frac{A}{B} = \frac{A''}{B''}$$

where

$A'' = A' + m' +$ part of Yoke Adj, and

$B'' = B' + m' +$ part of Yoke Adj.

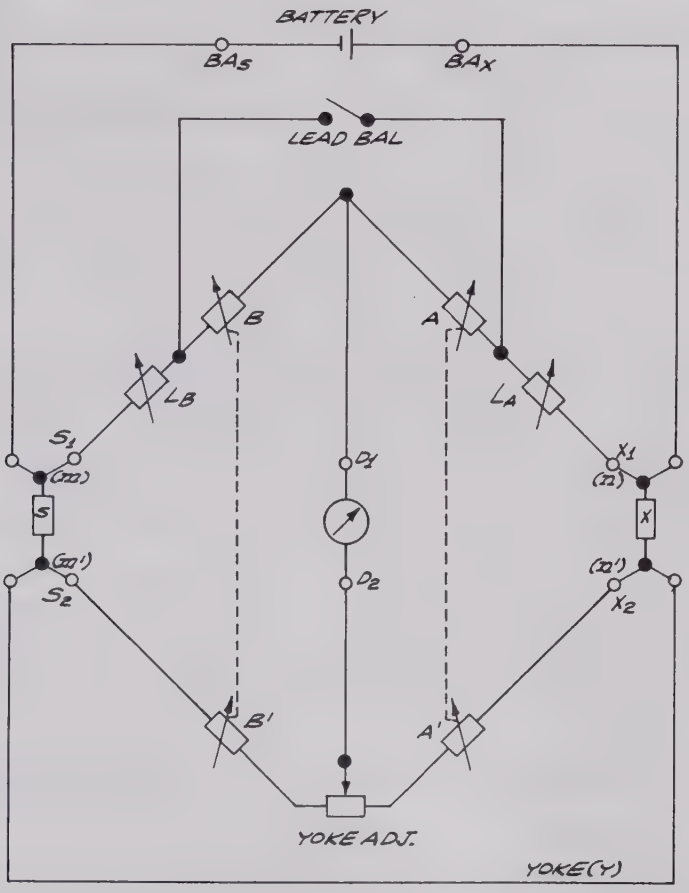


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*Fig. 4–Simplified schematic diagram showing rearrangement of Fig. 3.*

This condition will produce a balance of the ratio set provided that the lead-balance resistances that are part of the ratio-set arms have the same ratios also. Thus,

$$\frac{X}{S} = \frac{A}{B} = \frac{A''}{B''} = \frac{n + L_A}{m + L_B}$$

## 6B. Types of Measurements

There are many excellent publications that review the basic principles involved in precision Kelvin bridge measurements. Some of these publications are listed in the Preface. The reader of these publications will soon discover that there are many approaches to the measurement problem and that the user must make a choice related to the desired accuracy of the measurement. A choice of methods must be made that takes into consideration the accuracy, speed, and available accessories. Sections 6C, 6D, and 6E describe the use of this ratio set in four different modes of double ratio set measurements.

## 6C. Basic Method

The basic method requires a minimum of effort and external accessories to obtain a reading. The limit of error for this type of measurement is ±0.002% (20 ppm).

To make a measurement by this method, proceed as follows:

(1) Connect the null detector, battery, resistance standard, and resistance under test as indicated in Fig. 3 and Section 5.

(2) Place the LEAD BAL switch in the MEAS position; set the A and B dials to the nominal ratio—that is, 1000:1000, 1000:100, etc.

(3) Set the $L_A$ and $L_B$ dials to the nominal ratio used for the A and B dials; use minimum settings that will result in the required ratio.

(4) With the BATTERY switch in the OFF position and the DETECTOR key locked down, zero the null detector.

(5) With the BATTERY switch in the NOR position, adjust the A ratio dials to obtain a preliminary balance. To minimize self-heating, place the BATTERY switch in the NOR position momentarily while making successive adjustments of the A ratio dials until the null detector is balanced.

(6) Place the LEAD BAL switch in the BAL position and then adjust the $L_A$ dials (and $L_B$ dials, if necessary) until the null detector is balanced.

> CAUTION: Close the battery circuit only momentarily during this procedure, and make sure that the ratio set current is less than one ampere.

(7) Place the LEAD BAL switch in the MEAS position and open the external yoke circuit. Adjust the YOKE ADJ control until the null detector is balanced.

(8) Close the external yoke circuit and adjust the A ratio dials until the null detector is balanced.

(9) Repeat steps 5 through 8 until the settings of the A ratio dials need not be changed, or until the required change in the settings is within the accuracy required for the measurement.

Note that the red numerals of the A ratio dials provide a direct reading in ppm when the actual value of the unknown is less than the nominal value of the unknown.

Note also that the final readings of the A and B ratio dials may be corrected using calibration data previously obtained for each position of the A and B ratio dials or calibration data obtained from a calibration

report. When using an L&N Report of Calibration for this purpose, the uncertainty of the measurement is limited to ±0.001% (10 ppm).

6D. Direct Substitution Method

This is the most accurate method because the measurement accuracy depends upon small changes of the ratio instead of upon the actual ratio. The limit of error of a measurement obtained by this method is within ±0.0001% (1 ppm).

The proper use of this method requires the use of two resistance standards: a working standard (S) and a dummy standard (D). Also, the resistance under test (X) should not differ from the resistance of the working standard (S) by more than 0.1%. The dummy standard (D) should have a minimum temperature coefficient; however, its actual resistance need not be known. The actual resistance of the working standard (S) must be known within the accuracy and precision desired for the final determination of the actual value of the resistance under test (X).

To make the measurement, proceed as follows:

(1) Make the necessary connections of the accessories as indicated in Fig. 3, and establish the bridge current indicated in Table III for 4-terminal DRS measurement.

(2) Connect the dummy standard (D) into the normal "S" position and the working standard (S) in the normal "X" position. Place the LEAD BAL switch in the MEAS position.

(3) Set the A ratio dials to 99X.0000* and the B ratio dial to the setting required to obtain the nominal ratio to be measured. Set the $L_A$ and $L_B$ dials to the nominal ratio used for the A and B dials; use minimum settings to obtain the ratio.

(4) With the BATTERY switch in the OFF position and the DETECTOR key locked down, zero the null detector.

(5) With the BATTERY switch in the NOR position, adjust the last five A ratio dials to obtain a preliminary balance; to minimize self-heating, place the BATTERY switch in the NOR position momentarily while making successive adjustment of the dials until the null detector is balanced.

(6) Place the LEAD BAL switch in the BAL position and then adjust the $L_A$ dials (and $L_B$ dials, if necessary) until the null detecor is balanced.

> CAUTION: Close the battery circuit only momentarily during this procedure, and make sure that the ratio set current is less than one ampere.

*Setting the first three dials to 99X permits the final balance of range ±0.1% from nominal without changing the settings of the first two dials.

(7) Place the LEAD BAL switch in the MEAS position and open the external yoke circuit. Adjust the YOKE ADJ control until the null detector is balanced.

(8) Close the external yoke circuit and readjust the A ratio dials, if necessary, until the null detector is balanced.

(9) Repeat steps 5 through 8 until the settings of the A ratio dials need not be changed, or until the required change in the settings is within the accuracy required for the measurement.

(10) Record the final settings of the A ratio dials as Reading 1.

(11) Disconnect the working standard (S) from the normal "X" position and replace it with the resistance under test (X). Repeat the balancing procedure of steps 5 through 9, using the same leadwires that were used to connect the working standard (S) to the ratio set.

(12) Record the final settings of the A ratio dials as Reading 2.

(13) Compute the actual deviation of the unknown resistance from its nominal value by means of the following equation:

$$C_X = \text{Reading 2} - \text{Reading 1} + C_S$$

where

$C_X$ = deviation in ppm of the unknown resistance (X) from its nominal value

$C_S$ = deviation in ppm of the working standard (S) from its nominal value

Reading 2 = reading in ppm of the ratio of the unknown resistance (X) to the dummy resistance (D)

Reading 1 = reading in ppm of the ratio of the working standard (S) to the dummy standard (D).

For example, assume that an unknown resistance (1 ohm nominal) is measured by the direct substitution method and that the following data was obtained:

Certified value of working standard (S) at working temperature = 1.000009 ohms

therefore

$C_S = +9$ ppm

Reading 2 = 99X.0162 = + 16.2 ppm

Reading 1 = 99X.0027 = + 2.7 ppm

$$C_X = \text{Reading 2} - \text{Reading 1} + C_S$$

$$C_X = +16.2 \text{ ppm} - (2.7 \text{ ppm}) + 9 \text{ ppm}$$

$$C_X = +22.5 \text{ ppm}.$$

Therefore,

$$X = 1.0000225 \text{ ohms}.$$

## 6E. Zero Compensation Method

When the proper standards are not available to permit use of the direct substitution method, the true zero setting of the ratio set can be determined for nominal ratios and, consequently, a corresponding correction can be applied to the measurement reading. The techniques for determining the zero correction are referred to as the "Interchange or Double Substitution" method for a 1:1 ratio and the "Rotating Standards" method for nominal ratios of 2:1 to 10:1.

### (1) Interchange or Double Substitution Method

To determine the true zero setting of the ratio set (correction) by this method, proceed as follows:

(1) Make the connections indicated in Fig. 3, using two nominally equal 100-ohm N.B.S. resistance standards, and provide the bridge voltage indicated in Table III for 4-terminal DRS measurement.

(2) Place the LEAD BAL switch in the MEAS position. Then set the A ratio dials to 99X.0000 and the B ratio dial to 10.

(3) Set the $L_A$ and $L_B$ dials to the nominal ratio used for the A and B dials; use minimum settings that will result in the required ratio—for example, $L_A$ dials at 1.000 and $L_B$ dials at 1.0.

(4) With the BATTERY switch in the OFF position and the DETECTOR key locked down, zero the null detector.

(5) With the BATTERY switch in the NOR position, adjust the A ratio dials to obtain a preliminary balance; to minimize self-heating, place the BATTERY switch in the NOR position only momentarily while making successive adjustments of the dials until the null detector is balanced.

(6) Place the LEAD BAL switch in the BAL position and then adjust the $L_A$ dials (and $L_B$ dials, if necessary) until the null detector is balanced.

> CAUTION: Close the battery circuit only momentarily during the procedure and make sure that the ratio set current is less than one ampere.

(7) Place the LEAD BAL switch in the MEAS position and open the

external yoke circuit. Adjust the YOKE ADJ control until the null detector is balanced.

(8) Close the external yoke circuit and adjust the A ratio dials until the null detector is balanced.

(9) Repeat steps 5 through 8 until the settings of the A ratio dials need not be changed, or until the required change in the settings is within the accuracy required for the measurement.

(10) Record the final settings of the A ratio dials as Reading 1.

(11) Interchange the S and X resistance standards; then repeat steps 5 through 9.

(12) Record the final settings of the A ratio dials as Reading 2.

(13) The average of these two readings is the true zero setting of the A ratio dials for an exact 1:1 ratio where the first two A ratio dials are set at 9 and the B ratio dial is set at 10; the ratio-set error is the difference between this setting and 1000 ohms.

For example, assume that

Reading 1 = 99X.0201 ohms

Reading 2 = 99X.0107 ohms

Total of Reading 1 + Reading 2 = 2000.0308 ohms

Average Reading = 2000.0308/2 = 1000.0154

Ratio set error = +0.0154 ohm

Ratio set error = +15.4 ppm.

The ratio set error as determined by this procedure should be subtracted algebraically from measurements (readings) obtained with the 1000:1000 ratio and this result should be added algebraically to the error of the resistance standard to which the unknown resistance was compared. For example, assume that:

Calibrated value of resistance standard = 999.9993 ohms or −0.7 ppm

Measurement (final reading of A ratio dials) = 1000.0026 ohms or +2.6 ppm

True zero setting of ratio set (1:1 ratio) = 1000.0154 ohms or +15.4 ppm.

Then

X = Measurement (ppm) – Zero Setting (ppm) + Resistance Standard (ppm)

X = (+2.6 ppm) – (15.4 ppm) + (–0.7 ppm)

X = –13.5 ppm

X = 999.9865 ohms.

(2) Rotating Standards Method

NOTE: This is a 2-terminal measurement, but the corrections thus determined are valid for both 2 and 4-terminal measurements.

To determine the true zero setting of the ratio set by this method, proceed as follows:

(1) Assume that the true zero setting is to be determined for a 1000:100 (10:1) ratio.

(2) Make the connections indicated in Fig. 5, using eleven nominally equal 100-ohm N. B. S. resistance standards, and provide the battery current indicated in Table III for 2-terminal DRRS measurement.

(3) Place the LEAD BAL switch in the MEAS position. Then set the A ratio dials to 99X.0000 and the B ratio dial to 1 (100 ohms).

(4) Set the $L_A$ and $L_B$ dials to the nominal ratio used for the A and B dials; use minimum settings that will result in the required ratio —for example, $L_A$ dials at 10.000 and $L_B$ dials at 1.0.

(5) With the BATTERY switch in the OFF position and the DETECTOR key locked down, zero the null detector.

(6) With the BATTERY switch in the NOR position, adjust the A ratio dials to obtain a preliminary balance; to minimize self-heating, place the BATTERY switch in the NOR position only momentarily while making successive adjustments of the dials until the null detector is balanced.

(7) Place the LEAD BAL switch in the BAL position and then adjust the $L_A$ dials (and $L_B$ dials, if necessary) until the null detector is balanced.

CAUTION: Close the battery circuit only momentarily during this procedure and make sure that the ratio set current is less than one ampere.

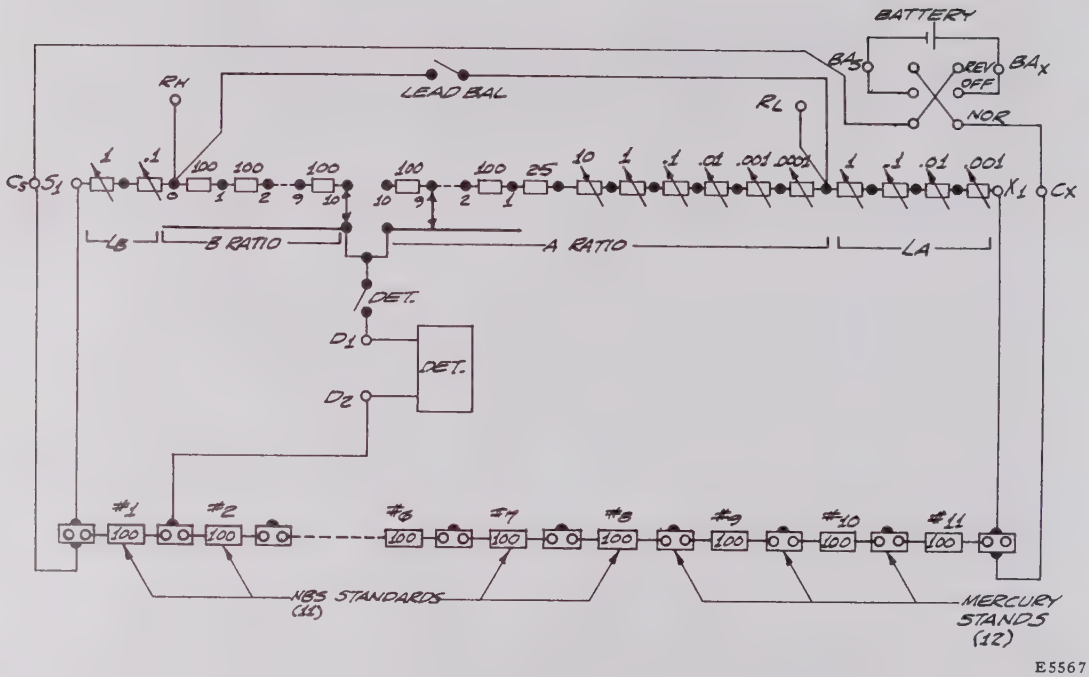



*Fig. 5–Schematic for determining bridge zero for 1000:100 ratio.*

(8) Place the LEAD BAL switch in the MEAS position and adjust the lower A ratio dials until the null detector is balanced (see Section 3G).

(9) Record the final settings of the A ratio dials as Reading 1.

(10) Interchange the No. 1 and No. 2 resistance standards, Fig. 5, and rebalance the A dials. Continue to interchange the resistance standards until each resistance standard (No. 2 through No. 11) occupies the extreme left position once—that is, the positions of the resistance standards, left to right, in Fig. 5 for

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reading 1 are | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Reading 2 are | 2 | 1 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Reading 3 are | 3 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Reading 4 are | 4 | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Reading 5 are | 5 | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 11 |
| Reading 6 are | 6 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 |
| Reading 7 are | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 |
| Reading 8 are | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 11 |
| Reading 9 are | 9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 11 |
| Reading 10 are | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 11 |
| Reading 11 are | 11 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

(11) The average of these eleven readings is the true zero setting of the A ratio dials for 1000:100 (10:1) ratio where the first two A ratio dials are set at 9 and the B ratio dial is set at 1; the ratio-set error is the difference between this setting and 1000 ohms.

For example, assume that

Reading 1 = 99X.0051
Reading 2 = 99X.0059
Reading 3 = 99X.0073
Reading 4 = 99X.0047
Reading 5 = 99X.0078
Reading 6 = 99X.0072
Reading 7 = 99X.0024
Reading 8 = 99X.0056
Reading 9 = 99X.0043
Reading 10 = 99X.0007
Reading 11 = 99X.0040

Total of Readings 1 through 11 = 11000.0550/11 = 1000.0050

Ratio set error = +0.0050 ohm

Ratio set error = +5.0 ppm.

The ratio set error as determined by this procedure should be subtracted algebraically from measurements (readings) obtained with the 1000:100 (10:1) ratio and this result should be added algebraically to the error of the resistance standard to which the unknown resistance was compared.

### (3) Zero Settings for Other Primary Ratios

True zero settings of the ratio set can be determined for other primary ratios in a manner similar to that outlined in Section 6E(2). For example: For a ratio of 5:1, six resistance standards would be used and only six readings would be taken. For additional information about this particular determination, refer to any of the references listed in the Preface.

## 7. OPERATION AS A DIRECT READING RATIO SET

### 7A. Substitution Method Involving a Dummy Resistance Standard

The following procedure for measuring the ratio of an unknown resistance to a known standard resistance while using this instrument as a direct reading ratio set (DRRS) requires the use of a dummy resistance standard in a substitution method. This method does not require the determination of the true zero setting of the ratio set and does not require lead compensation. An additional convenience is that only one reading is required, which is automatically corrected for the deviation of the resistance

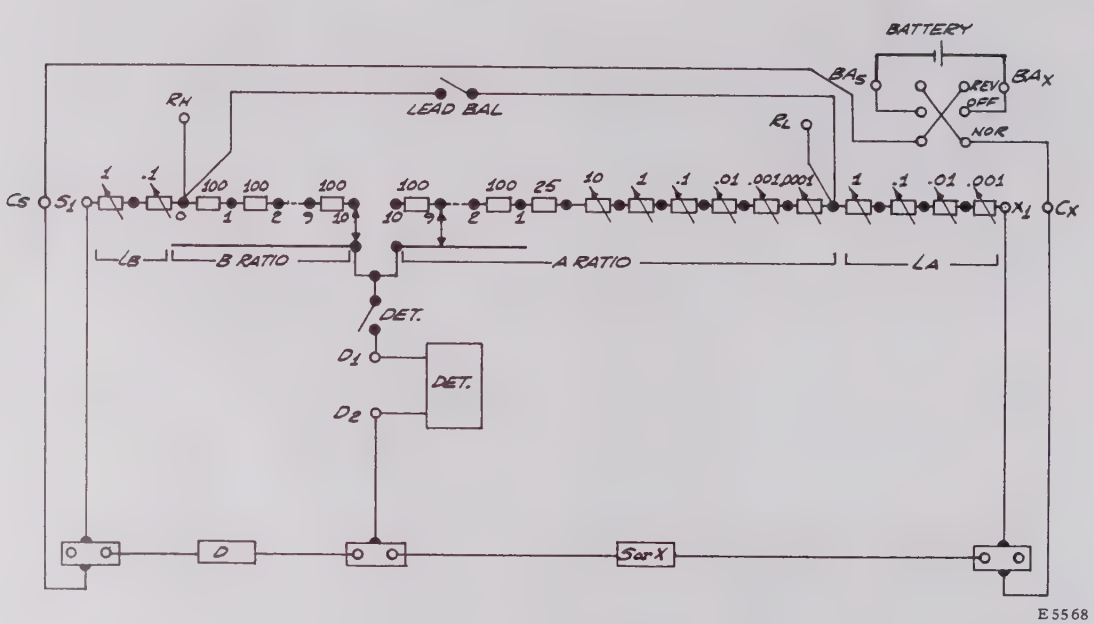



*Fig. 6–Direct reading ratio set measurements.*

standard from its nominal resistance. The following procedure is specifically applicable to the 1:1 ratio but the technique of the procedure is applicable to any ratio that can be obtained with this ratio set.

> IMPORTANT: Maximum accuracy can be obtained by this procedure only if the lead resistances are as low as practicable and the $L_B$ lead balance dials are set at a minimum setting.

(1) Set the A ratio dials to 99X.0000 and the B ratio dial to 10 to obtain a 1000:1000 or 1:1 ratio. Set the $L_A$ and $L_B$ dials to 1.000 and 1.0, respectively.

(2) Connect a dummy N. B. S. resistance standard in the "S" position and a working resistance standard in the "X" position as indicated in Fig. 6.

(3) Change the A ratio dials by an amount and in the same direction as the working resistance standard deviates from its nominal value. For example: If the working resistance standard is 10 ppm low, set the A ratio dials to 999.9900; if it is 30 ppm high, set the A ratio dials to 99X.0300.

(4) With the A ratio dials set properly, adjust the $L_A$ dials until the null detector is balanced.

(5) Replace the working standard resistance with the unknown resistance. Connect the unknown resistance with the same leads that were used to connect the working standard resistance.

(6) Adjust the A ratio dials until the null detector is balanced.

(7) Read the ratio in ppm from the final settings of the A ratio dials. For example: A final reading of 99X.0700 means that the unknown resistance (X) is 70.0 ppm greater than its nominal value, while a final reading of 999.9300 means that the unknown resistance is 70.0 ppm lower than its nominal value, and the red numbers 69X on the last three dials indicate directly the 70.0 ppm deviation.

> NOTE: The final reading contains an inaccuracy that is a function of the settings of the $L_B$ dials and the deviation of the unknown resistance (X) from its nominal value.
>
> If the $L_B$ dials are set at less than 2 ohms and the deviation of the unknown resistance (X) from its nominal value is less than 1.0% (10,000 ppm), the limit of error is 20 ppm. If the $L_B$ dials are set at less than 2 ohms and the deviation of the unknown resistance from its nominal value is less than 0.1%, the limit of error is 2 ppm. If the $L_B$ dials are set at less than 1 ohm and the deviation of the unknown resistance from its nominal value is less than 0.01%, then the limit of error is 0.2 ppm.

## 7B. Comparison of Two-Terminal Resistances by Interchange Method

In this method, two readings are taken using the connections indicated in Fig. 6: one reading with the resistance standard in position X and the unknown resistance in position S and a second reading with the resistances interchanged. An accuracy of 1 ppm can be obtained (ratio set error being taken into account in the equation) if the values of the resistances are within 0.1% of each other.

The correction in ppm of the unknown can be determined by the following equation:

$$C_X = \frac{\text{Reading 2} - \text{Reading 1}}{2} + C_S$$

where

$C_X$ = Correction in ppm to Nominal Value of X

Reading 1 = Reading in ppm with S connected to $X_1$ terminal

Reading 2 = Reading in ppm with X connected to $X_1$ terminal

$C_S$ = Correction in ppm to Nominal Value of S.

To compare two-terminal resistances by the interchange method, proceed as follows:

(1) Make the connections indicated in Fig. 6, and provide the battery voltage indicated in Table III for 2-terminal DRRS measurement.

(2) Set the A ratio dials to 99X.0000 and the B ratio dial to 10.

(3) Connect a shorting link between the two end mercury cup stands, shorting the two resistances S and X.

(4) Place the LEAD BAL switch in the BAL position. Then adjust the $L_A$ and $L_B$ dials until the null detector is balanced; use the minimum positions of both dials to obtain balance of the null detector.

(5) Remove the shorting link and then place the LEAD BAL switch in the MEAS position.

(6) Adjust the A ratio dials until the null detector is balanced. Record the positions of the A ratio dials as Reading 1.

(7) Interchange the standard (S) and unknown (X) resistances.

(8) Adjust the A ratio dials until the null detector is balanced. Record the positions of the A ratio dials as Reading 2.

(9) Substitute the proper values in the following equation and solve for $C_X$, which is the correction in ppm to the nominal value of X.

$$C_X = \frac{\text{Reading 2} - \text{Reading 1}}{2} + C_S$$

For example, assume that an unknown resistance X (1000 ohms nominal) was compared by the interchange method with a 1000.0200-ohm N.B.S. resistance standard S and the following data was obtained.

$$C_S = +20 \text{ ppm}$$

$$\text{Reading 1} = 99X.0120 = +12 \text{ ppm}$$

$$\text{Reading 2} = 999.9860 = -14 \text{ ppm}$$

then

$$C_X = \frac{(-14 \text{ ppm}) - (+12 \text{ ppm})}{2} + 20 \text{ ppm}$$

$$C_X = -13 \text{ ppm} + 20 \text{ ppm} = +7 \text{ ppm}$$

therefore

$$X = 1000.0000 + 7 \text{ ppm} = 1000.0070 \text{ ohms.}$$

## 8. MAINTENANCE

No special maintenance is required for this ratio set. The top plate and binding posts should be protected with a vinyl cover (L&N Part No. 095148) to prevent the accumulation of dust when the ratio set is not in use.

Under normal laboratory conditions the insulating parts of the binding posts will not require cleaning. However, if the binding posts become contaminated, clean them thoroughly with a mild detergent solution. Drying of the binding posts may be accelerated by the use of clean isopropyl alcohol.

## 9. REPLACEMENT PARTS

The parts of this ratio set that may require replacement are the heads of the binding posts (L&N Part No. 002199) and the vinyl cover (L&N Part No. 095148).

# APPENDIX

## OTHER TYPES OF MEASUREMENTS AND USES

### A1. PRECISION PLATINUM RESISTANCE THERMOMETER MEASUREMENTS

The 4398-M can be used with a platinum resistance thermometer, such as the L&N 8163 or equivalent, to make precise measurements of temperature. As indicated in Fig. A1, the only auxiliary equipment required is a two-terminal resistance box. The box need not be accurate but it must have a resolution that is consistent with the desired accuracy of measurement. It must also be stable during the entire time the measurements are made.

For example, if the nominal resistance of the thermometer is 25.5 ohms at the ice point temperature, and if measurements are to be made to the nearest 0.01°C, then the resolution of the resistance box should permit setting the box to within approximately 0.001 ohm of the 25.5 ohm nominal total.

As shown in Fig. A1, the resistance box is connected in the standard (S) side of the 4398-M and the thermometer in the unknown (X) side. With the thermometer at the ice point, the dials of the 4398-M are set at 100:100 if subsequent measurements are to be made above 0°C. Set the B and A Ratio dials at 1000:99X.0000 if subsequent measurements are to be made below 0°C. The normal procedure for balancing the leads is then followed, except the auxiliary resistance box is used for balancing where the normal procedure specifies balancing with the A Ratio dials. The 4398-M is now set to read a ratio of unity for the $R_T/R_O$ point when $R_T$ is equal to $R_O$.

To read the ratio of $R_T/R_O$ at any point above or below $R_O$, insert

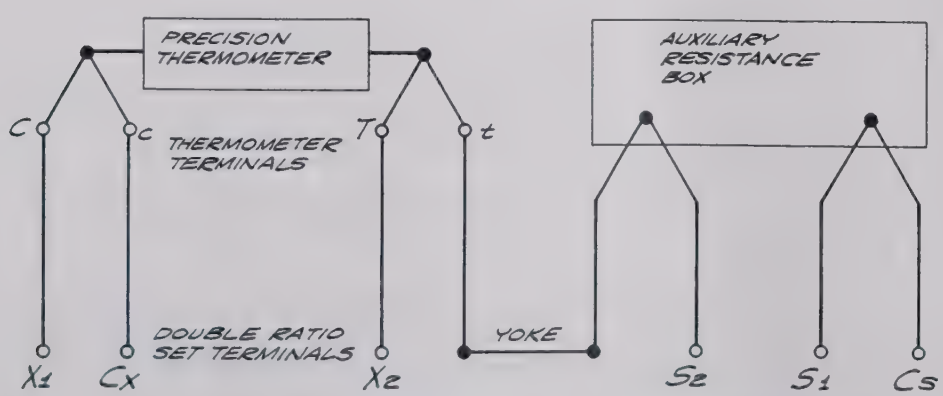



*Fig. A1–Connections to bridge for resistance thermometer measurements.*

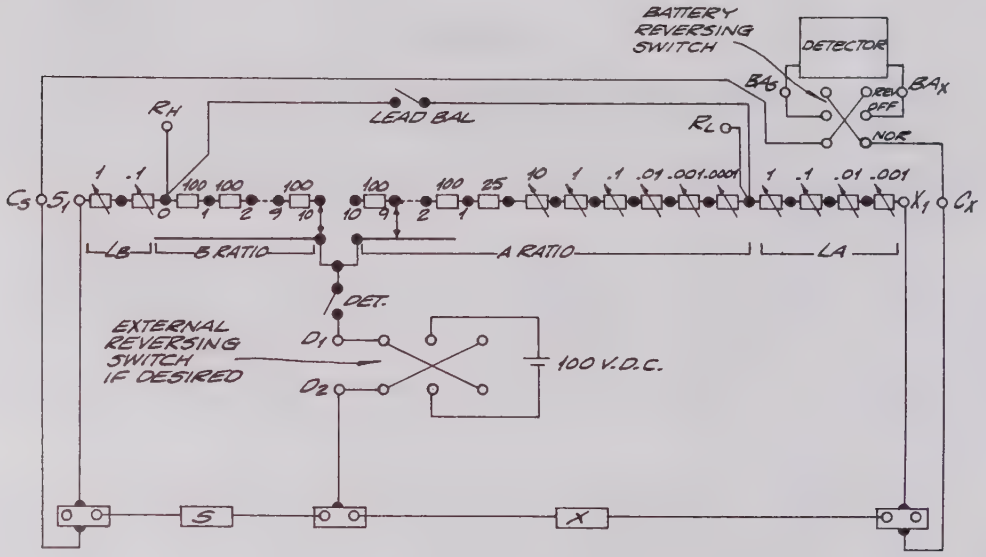



*Fig. A2–Direct reading ratio set connections for measurements between 0.1 megohm and 1.0 megohm.*

the thermometer in the new invironment and rebalance the measurement using the A Ratio dials on the 4398-M. Do not change the setting of the auxiliary resistance box and the lead balance dials of the 4398-M.

The number obtained through this technique is accurate to within 1 or 2 steps on the 6th dial of the 4398-M.

## A2. USE AS RESISTANCE BOX

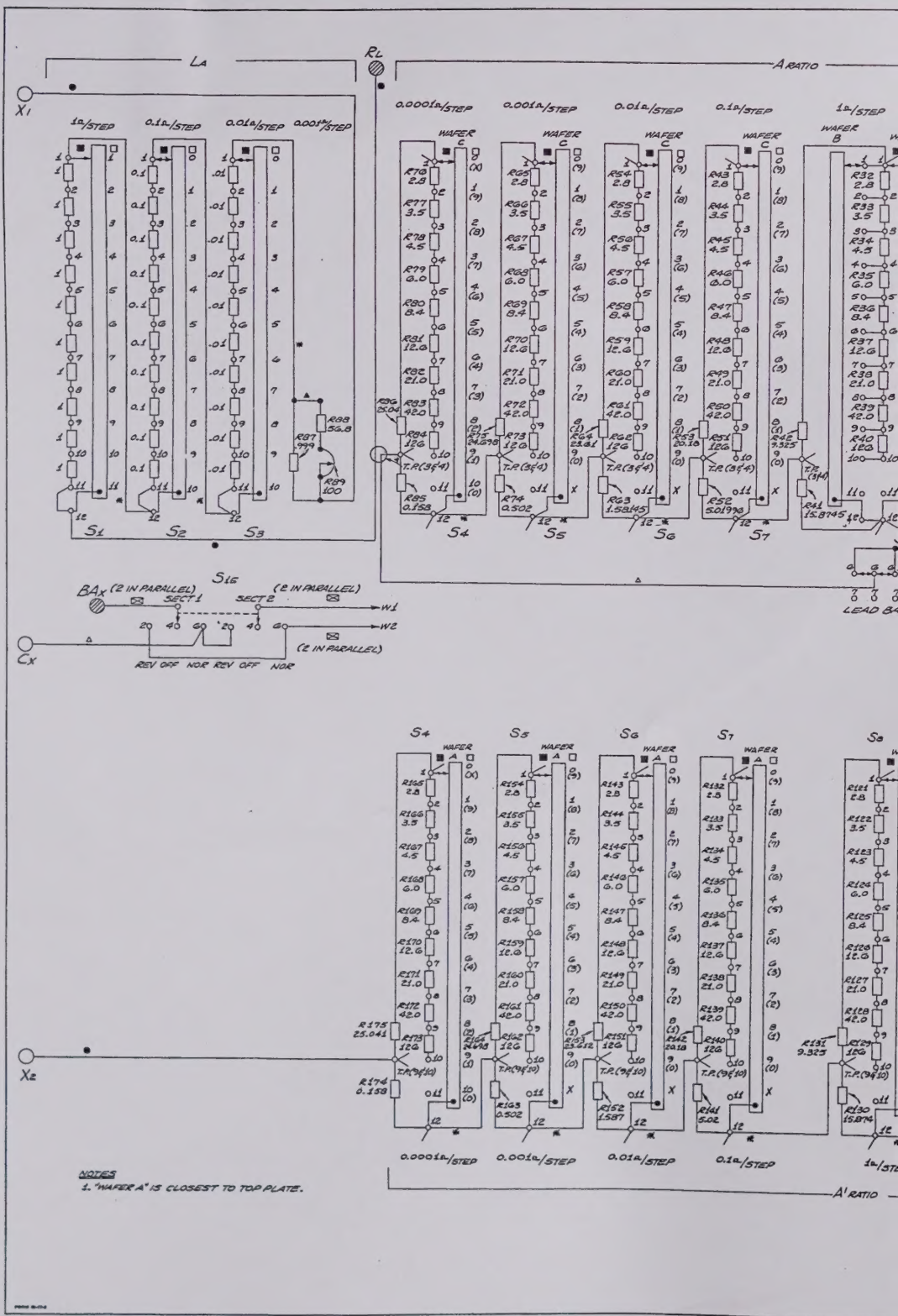
Eight decades of the A ratio can be used as a resistance box with a range of 100 to 2111.1110 ohms in steps of 0.0001 ohm and with an accuracy of 0.003% for changes from the minimum setting of a nominal 100 ohms. To use this ratio set as a resistance box, make connections to the $R_L$ and $R_H$ binding posts.

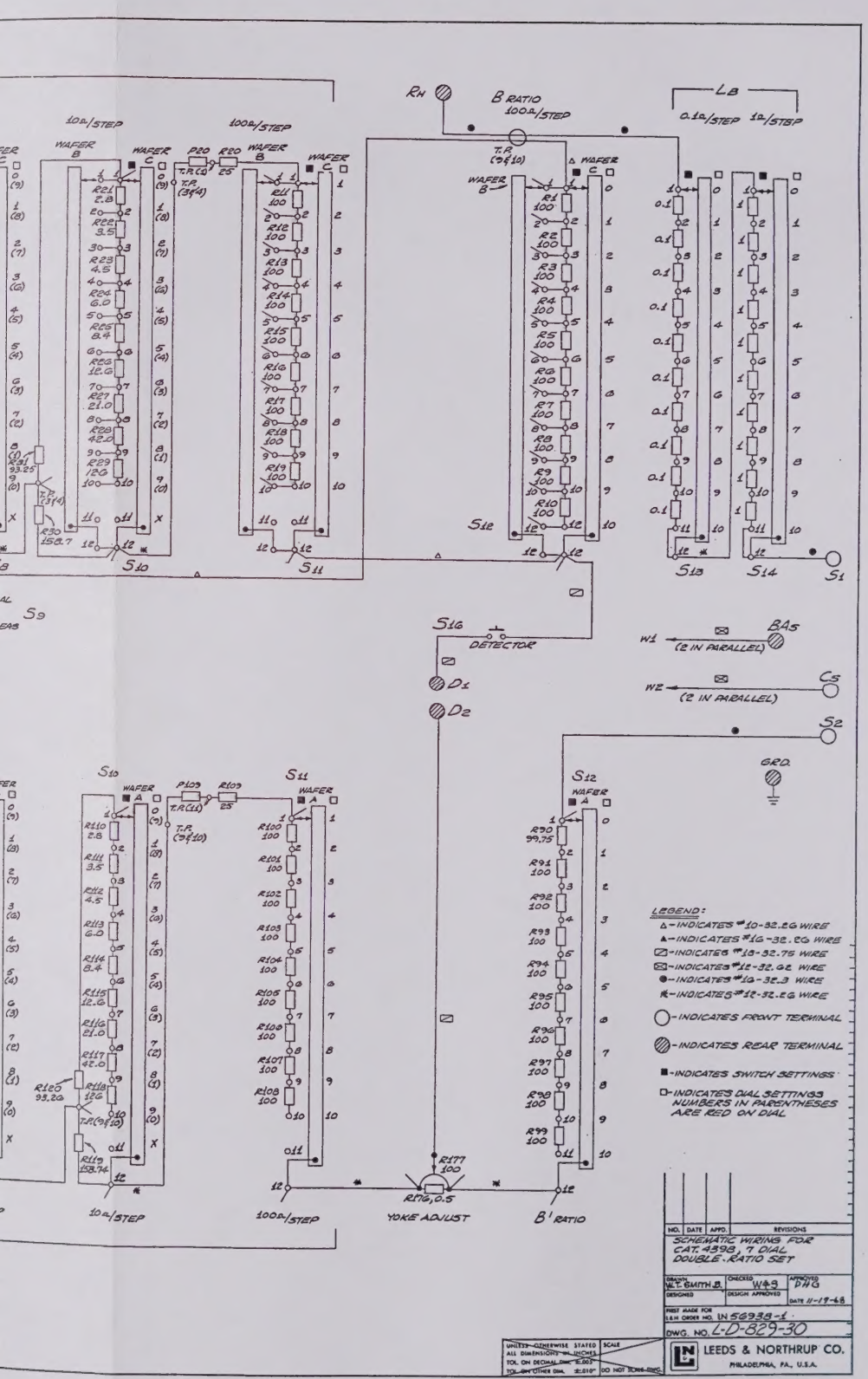
## A3. MEASUREMENTS BETWEEN 0.1 AND 1.0 MEGOHM

This ratio set can also be used for measurements of two-terminal resistors having values between 0.1 and 1.0 megohm.

Connections for this type of measurement are shown in Fig. A2. Note that this figure indicates that the orientation of the detector and the battery is reversed.

An external reversing switch, such as the L&N 3294 Pinch-Type Double-Pole Double-Throw Switch, can be used to connect a maximum of 100 volts dc to the $D_1$ and $D_2$ binding posts of the ratio set. In this type of measurement, the DETECTOR key becomes the battery switch and the BATTERY switch becomes the detector key.


LA
RL
A RATIO
X1
1Ω/STEP
0.1Ω/STEP
0.01Ω/STEP
0.001Ω/STEP
0.0001Ω/STEP
WAFER C
WAFER B
R88 56.8
R87 .979
R89 100
S1
S2
S3
S4
S5
S6
S7
S8
S16
BAx (2 IN PARALLEL)
SECT 1
SECT 2
(2 IN PARALLEL)
W1
W2
(2 IN PARALLEL)
Cx
REV OFF NOR REV OFF NOR
LEAD BA
X2
A' RATIO
NOTES
1. "WAFER A" IS CLOSEST TO TOP PLATE.




LEGEND:

△ - INDICATES #10-32.EG WIRE

▲ - INDICATES #16-32.EG WIRE

▨ - INDICATES #18-32.7S WIRE

⊠ - INDICATES #12-32.GE WIRE

● - INDICATES #16-32.3 WIRE

✱ - INDICATES #12-32.EG WIRE

○ - INDICATES FRONT TERMINAL

◍ - INDICATES REAR TERMINAL

■ - INDICATES SWITCH SETTINGS

□ - INDICATES DIAL SETTINGS NUMBERS IN PARENTHESES ARE RED ON DIAL

| NO. | DATE | APPD. | REVISIONS |
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